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ALUMINUM-LITHIUM ALLOY RESEARCH

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13. ABSTRACT *(Maximum 200 words)*

A recent Air Force program was focused on developing an isotropic aluminum-lithium alloy, having greater than two weight percent lithium. The addition of two weight percent lithium can reduce the density of aluminum by six percent and increase the modulus by twelve percent, thus offering significant benefits for weight savings in aerospace systems. The Air Force program was successful in that the difference between the longitudinal and 45 degree yield strengths of the experimental alloy was significantly reduced over that previously observed for alloys containing greater than two weight percent lithium, i.e., only a 10% variation compared with 20-25% for commercially available alloys. The alloy, designated AF/C-498 has the composition of Al-2.7Cu-2.1Li-0.6Zn-0.3Mn-0.3Mg-0.5Zr and the standard aging treatment was to solution heat treatment, quench, stretch 6% and age for 24 hours at 150 degrees C. Unfortunately the elongation after this aging treatment is lower than the minimum of five percent that is desirable for aerospace applications.

The research under this contract was concerned with examining aging treatments that would improve the elongation with no sacrifice in strength or isotropic properties. The material studied was received from the Air Force Materials as 0.5 inch plate. The plate was marked that it had been solutionized at 540 degrees C, quenches, stretched 6%, and aged at 300 degrees F (149 degrees C) for 24 hours (T8).

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Introduction

Aluminum-lithium alloys offer attractive properties for aerospace applications due to their low density, good strength, and fatigue crack growth resistance. However, these alloys have higher levels of anisotropy in their mechanical properties than conventional aerospace aluminum alloys. The anisotropy of Al-Li alloys is due, in part, to the very sharp textures that are developed during rolling and the precipitation of the strengthening particles on specific habit planes.

A recent Air Force program was focused on developing an isotropic aluminum-lithium alloy, having greater than two weight percent lithium. The addition of two weight percent lithium can reduce the density of aluminum by six percent and increase the modulus by twelve percent, thus offering significant benefits for weight savings in aerospace systems. The Air Force program was successful in that the difference between the longitudinal and 45° yield strengths of the experimental alloy was significantly reduced over that previously observed for alloys containing greater than 2 weight percent lithium, i.e. only a 10% variation compared with 20-25% for commercially available alloys. The alloy, designated AF/C-489 has the composition of Al-2.7Cu-2.1Li-0.6Zn-0.3Mn-0.3Mg-0.05Zr and the standard aging treatment was to solution heat treat, quench, stretch 6% and age for 24 hours at 150°C. Unfortunately the elongation after this aging treatment is lower than the minimum of five percent that is desirable for aerospace applications.

The research under this contract was concerned with examining aging treatments that would improve the elongation with no sacrifice in strength or isotropic properties. The material studied was received from the AF Materials Dir. as 0.5" plate. The plate was marked that it had been solutionized at 540°C, quenched, stretched 6% and aged at 300° F (149° C) for 24 hours (T8).

Experimental Results and Discussion

Initial examination of the plate revealed that it was not in the T8 temper, but was in the T36 temper. Figure 1 shows bright field transmission electron micrographs and the (011) selected area diffraction pattern (SADP) of the as-received material. The SADP has spots from the aluminum matrix and Al_3Li (δ') precipitates and the bright field micrographs show the dislocation structure associated with the pre-age stretch. Figure 2 is a bright-field/dark-field pair, the dark field using a diffraction spot from the δ' precipitates. The very fine δ' is indicative of a naturally aged Al-Li alloy having approximately 2 wt.% Li. Figure 3 shows bright field micrographs of the as-received material using a (001) zone axis. These micrographs contain two types of dispersoids; the small ones are probably Al_3Zr and the larger ones are possibly $Al_{20}Cu_2Mn$. We haven't confirmed the composition of the dispersoids at this time but will accomplish this on the follow-on contract. Also note that the larger particles create deformation zones during the pre-age stretch, Figure 3-f.

Figure 4 presents the SADP, bright-field and centered dark-field transmission electron micrographs from the (001) zone axis of the AF/C-489 after aging for 24 hours at 150°C. These micrographs illustrate the presence of both Al_2CuLi (T_1) and Al_2Cu (θ'') as well as δ'. Some of the precipitates are composites, probably Al_3Li and Al_3Zr. Figure 5 presents the SADP, bright-field, and centered dark-field TEM's from slightly off the (011) zone axis

of AF/C-489 in the T8 temper and illustrates the "puckering" caused by θ" along the subgrain boundaries. At this time, we do not have corresponding TEM's of a high angle grain boundary.

The aging response at three different temperatures, 100°, 120°, and 150°C, of the as-received T36 plate was determined from hardness measurements, Figure 6. The lower aging temperatures, i.e. 100° and 120°C, were used in a two step aging study. Figure 7 shows the hardness curves as a function of aging at 150°C for samples given a first step aging treatment at 100°C for various times. Two step aging treatments for tensile tests were selected that produced similar hardness to the single 24 hour/150°C treatment. Similar hardness data for a 120°C first step aging are shown in Figure 8.

Both longitudinal and transverse tensile samples were machined from the as-received plate using ASTM standard E8 sub-sized tensile bars. They had a one inch gauge length and a nominal diameter of 0.25 inches. All samples were representative of the midplane of the plate. The thermal treatments and the results of the tensile tests are presented in Table I. It is obvious that the hardness results do not accurately predict the tensile properties, i.e. even though the hardness values were the same for the single-age and the selected treatments for the double-aged samples, the strengths were not always the same. However, one double-age treatment, 120°C for 8 hours followed by 21 hours at 150°C produced an almost equivalent strength to the 24 hour/150°C age, but with a 38% improvement in elongation, 7.43% versus 5.37%.

Scanning electron micrographs of the 150°C/24hr and 120°C/8hr/150°C/21hr are shown in Figure 9. The fracture surface for the single-aged sample is essentially perpendicular to the stress axis and primarily intergranular while the fracture surface for the double-aged sample is at approximately 45° to the stress axis and primarily transgranular. It is obvious that there is a difference in grain boundary structure, i.e. precipitate size and distribution and precipitate free zone width.

This preliminary study shows that a significant improvement in ductility can be obtained by modifying the heat treatment of this alloy from that originally used, i.e. 24 hours at 150°C. We believe that we can still improve the strength/elongation combination by optimizing the pre-age stretch and the double-age treatment and these studies are continuing under our new contract with TMC and with a grant from the Air Force Office of Scientific Research.

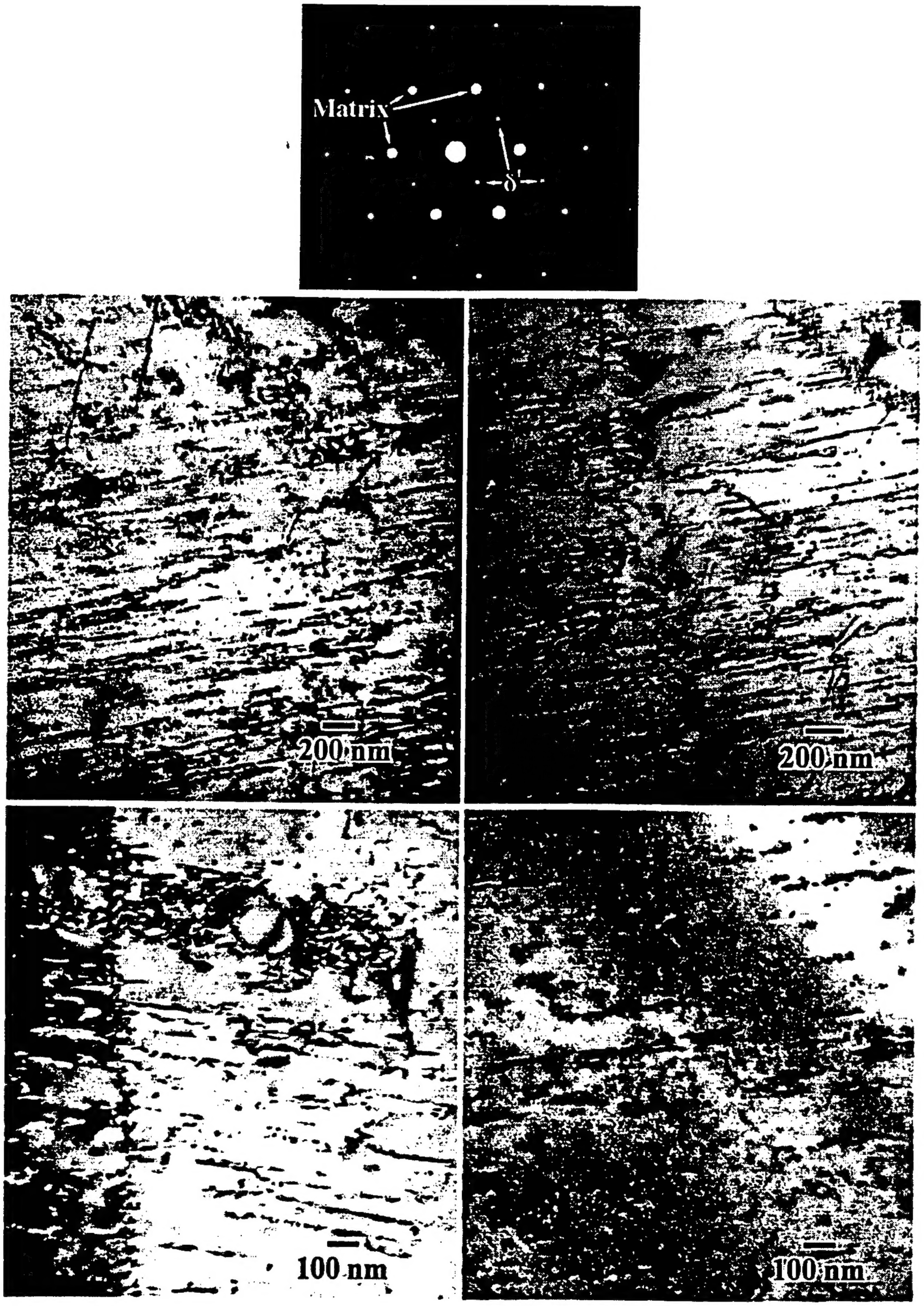
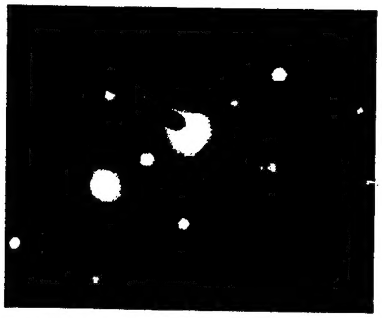
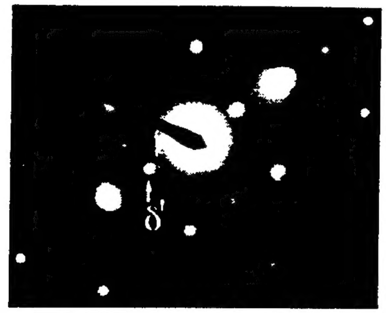


Figure 1: a) Selected area diffraction pattern (SADP) and b) Bright-field TEM micrographs (BFTEM) of the (011) zone axis for the as-received AF/C-489 alloy along the stretch direction.

Note that the (011) SADP indicates the presence of only the Al matrix and δ' precipitate spots while the BFTEM micrographs demonstrate the dislocation structure associated with the pre-age stretch.



Off (011) Zone Axis



Off (011) Zone Axis

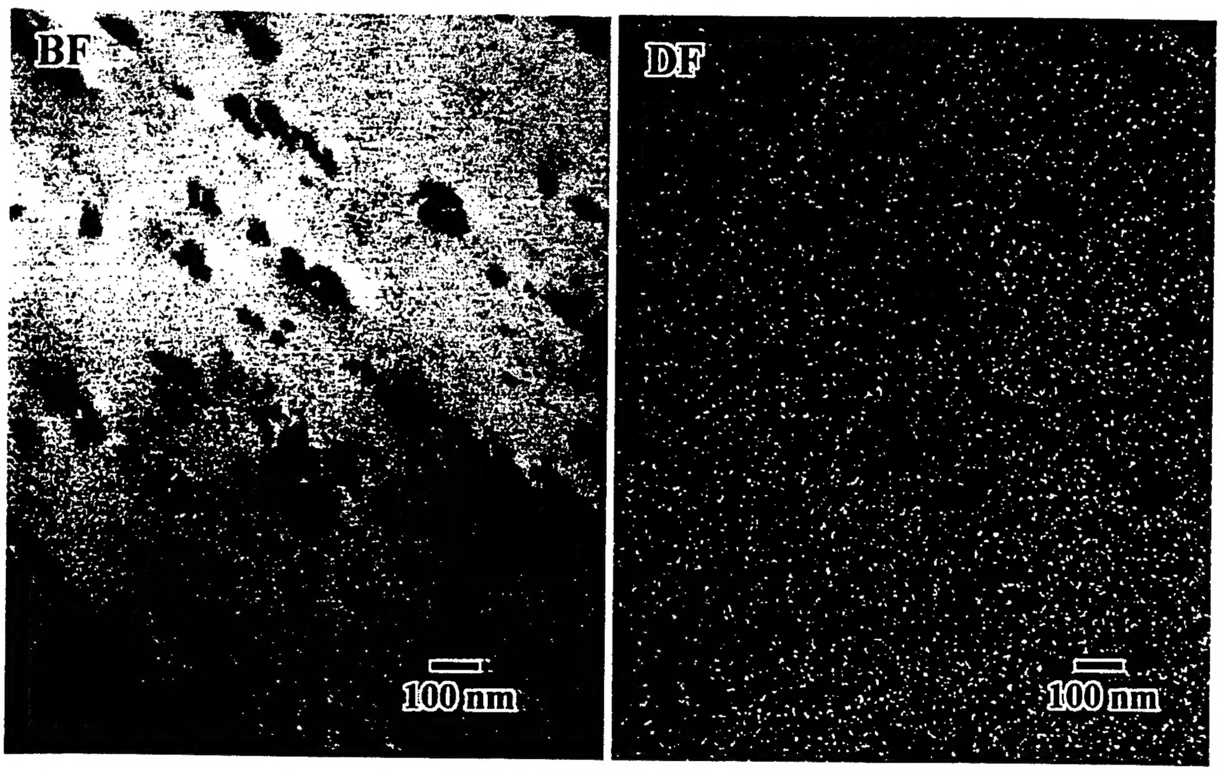


Figure 2) Off (011) zone axis SADP for the as-received AF/C-489 alloy along the stretch direction and bright-field and dark-field TEM micrographs ulitizing the transmitted and δ' precipitate diffracted beams, respectively.

Note the extremely fine δ' precipitate size and distribution in the dark-field TEM micrograph which is indicative of the T36 natural aging temper.

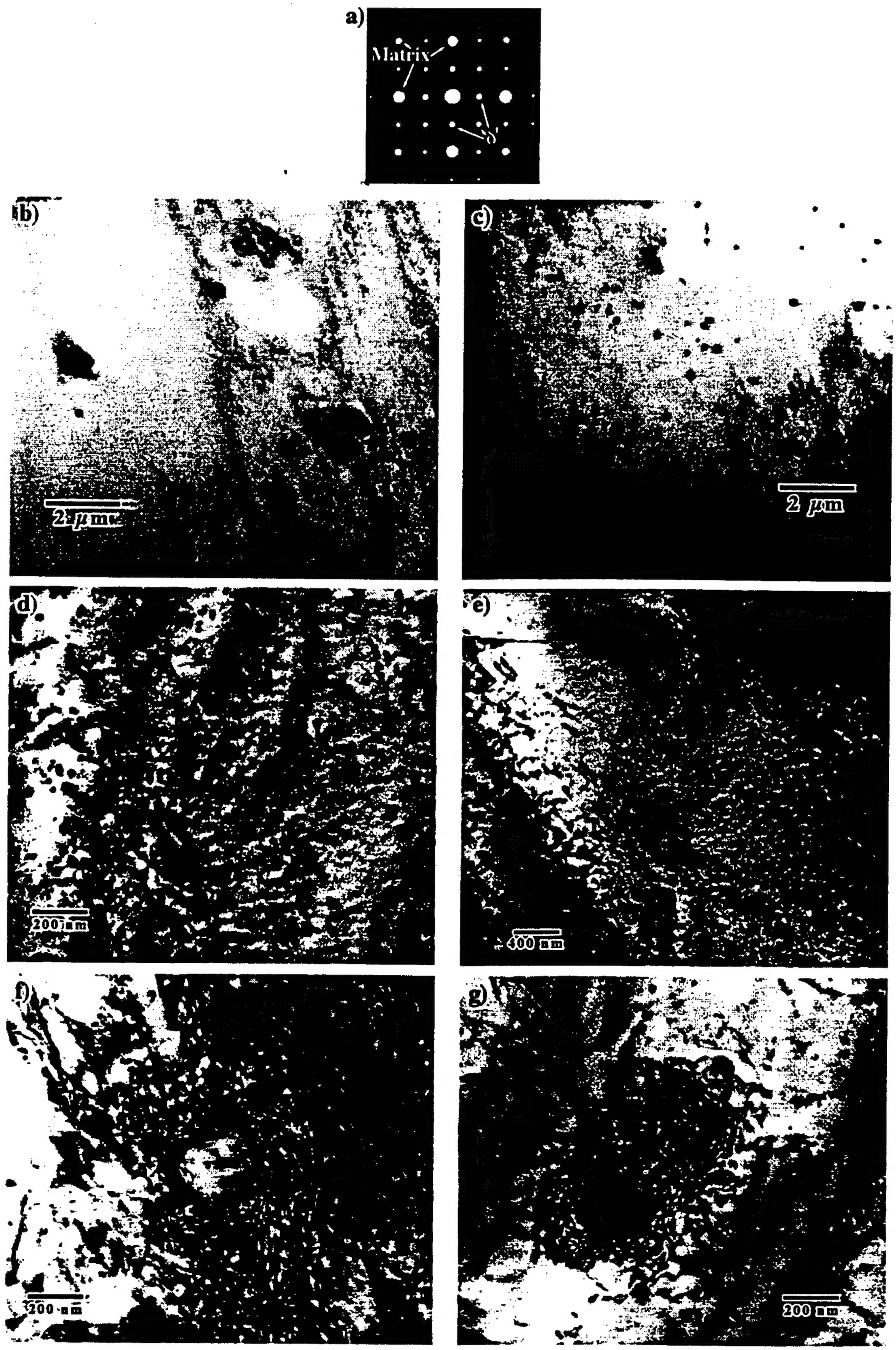


Figure 3: a) SADP of the (001) zone axis for the as-received AF/C-489 alloy in the through thickness direction. b/c) Low-magnification BFTEM micrographs demonstrating the varying disperoid sizes & distribution. d & e-g) BRTEM micrographs illustrating the dislocation structure associated with the pre-age stretch in the Al matrix and across various disperoids, respectively.

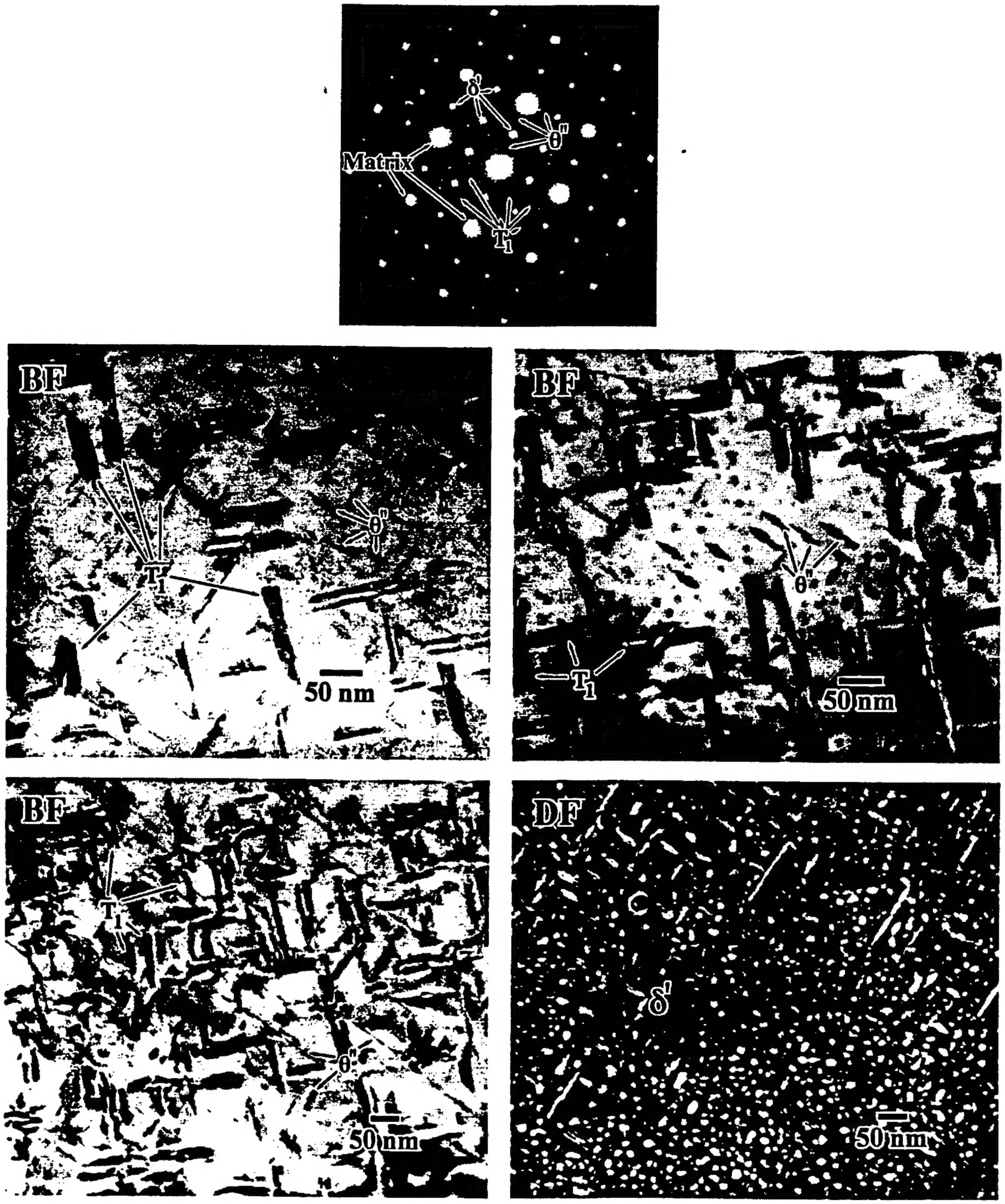


Figure 4: SADP, bright-field, and centered dark-field TEM micrographs from the (001) zone axis of the AF/C-489 alloy with a T8 temper at 150°C for 24 hours which illustrate the presence of both T_1 and θ" plates as well as δ' spheres and coatings along the interface between the precipitate plates and the matrix.

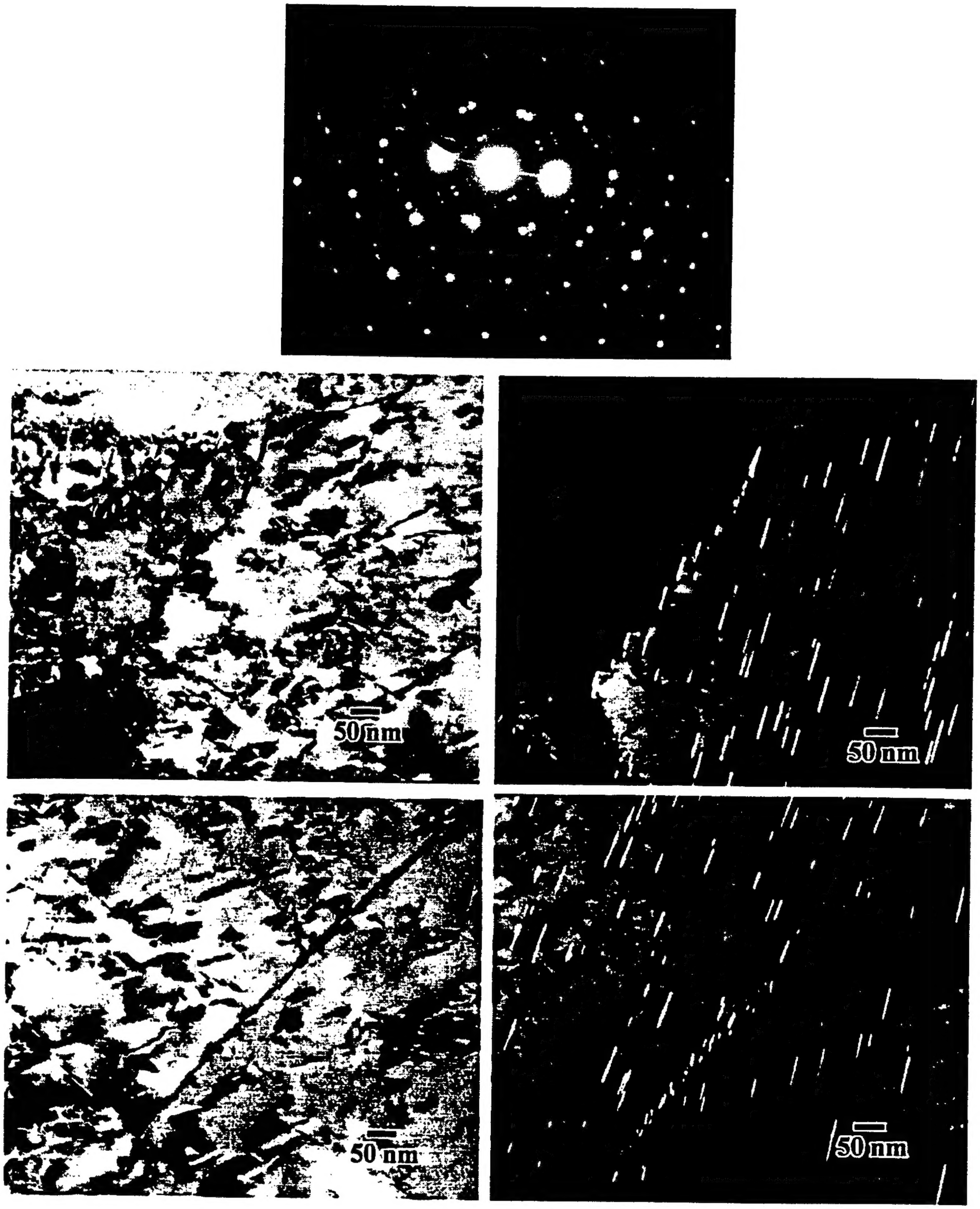


Figure 5: SADP, bright-field, and centered dark-field TEM micrograph series from slightly off the (011) zone axis for the AF/C-489 alloy with a T8 temper at 150°C for 24 hours which illustrate the puckering of θ" plates along the subgrain boundaries

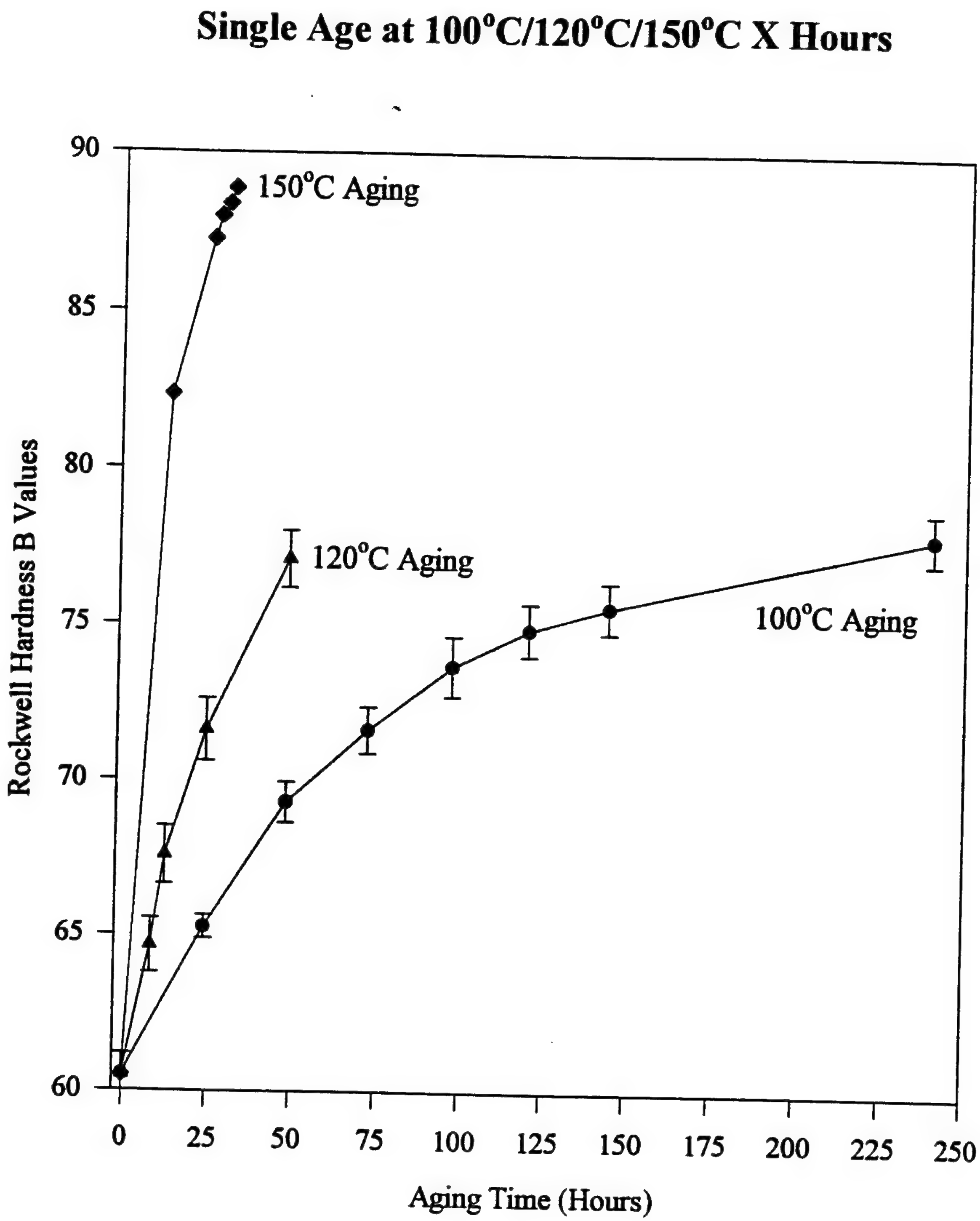


Figure 6: Rockwell B hardness versus aging time at various temperatures for AF/C 489-T36.

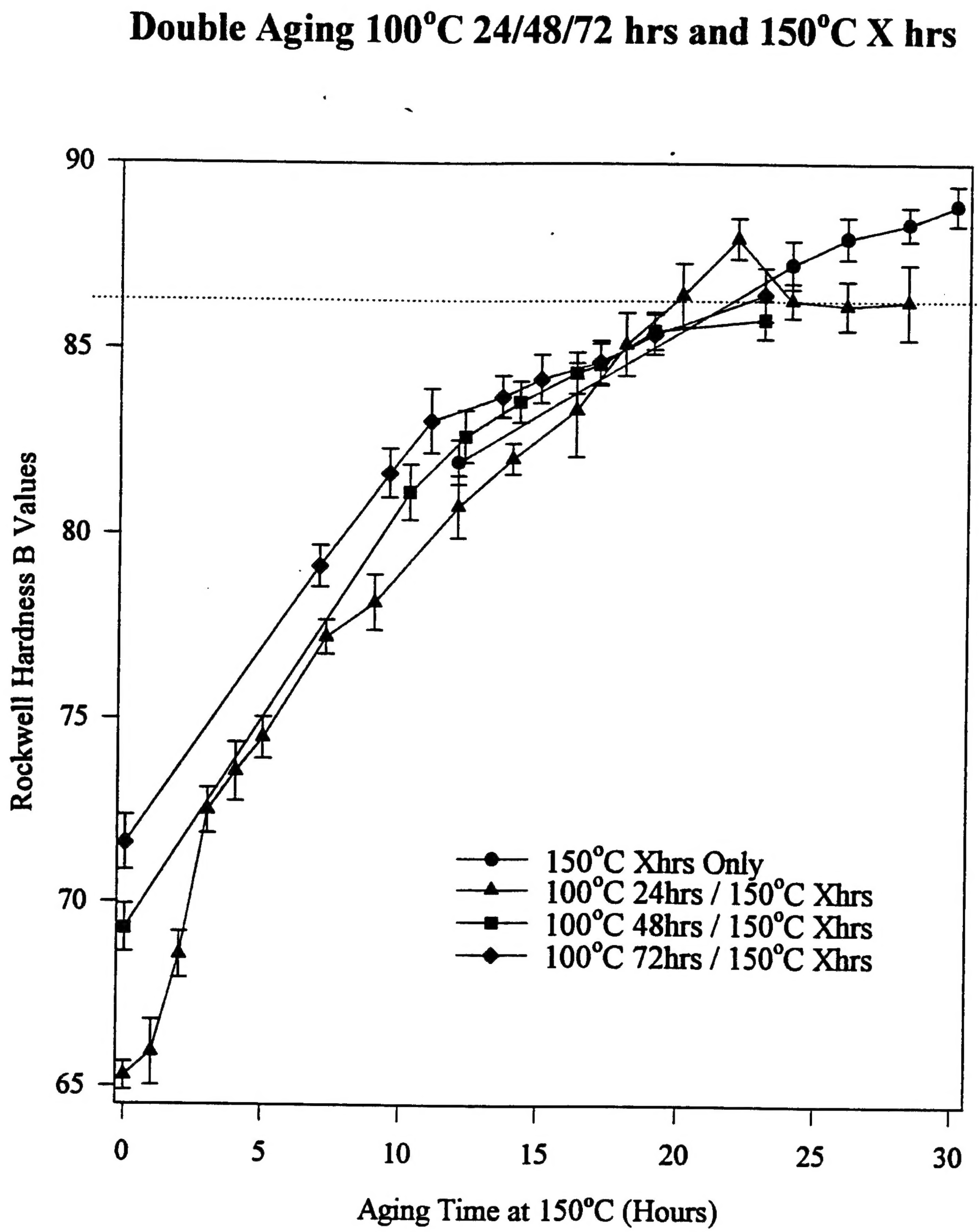


Figure 7: Rockwell B hardness versus aging time after various pre-aging treatments for AF/C 489.

Double Aging 120°C 8/12/24/48 hrs and 150°C X hrs

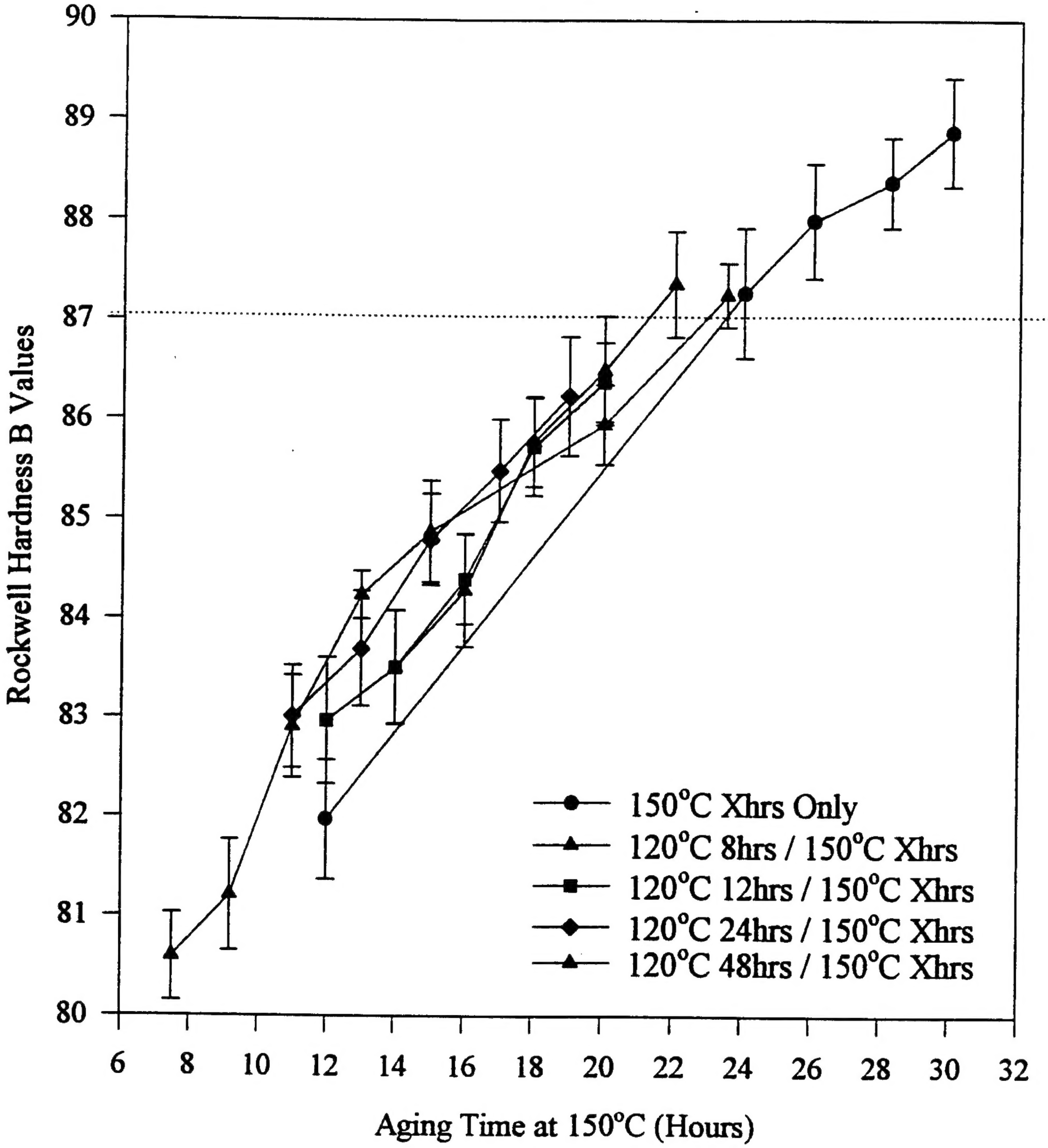


Figure 8: Rockwell B hardness versus aging time after various pre-aging treatments for AF/C 489.

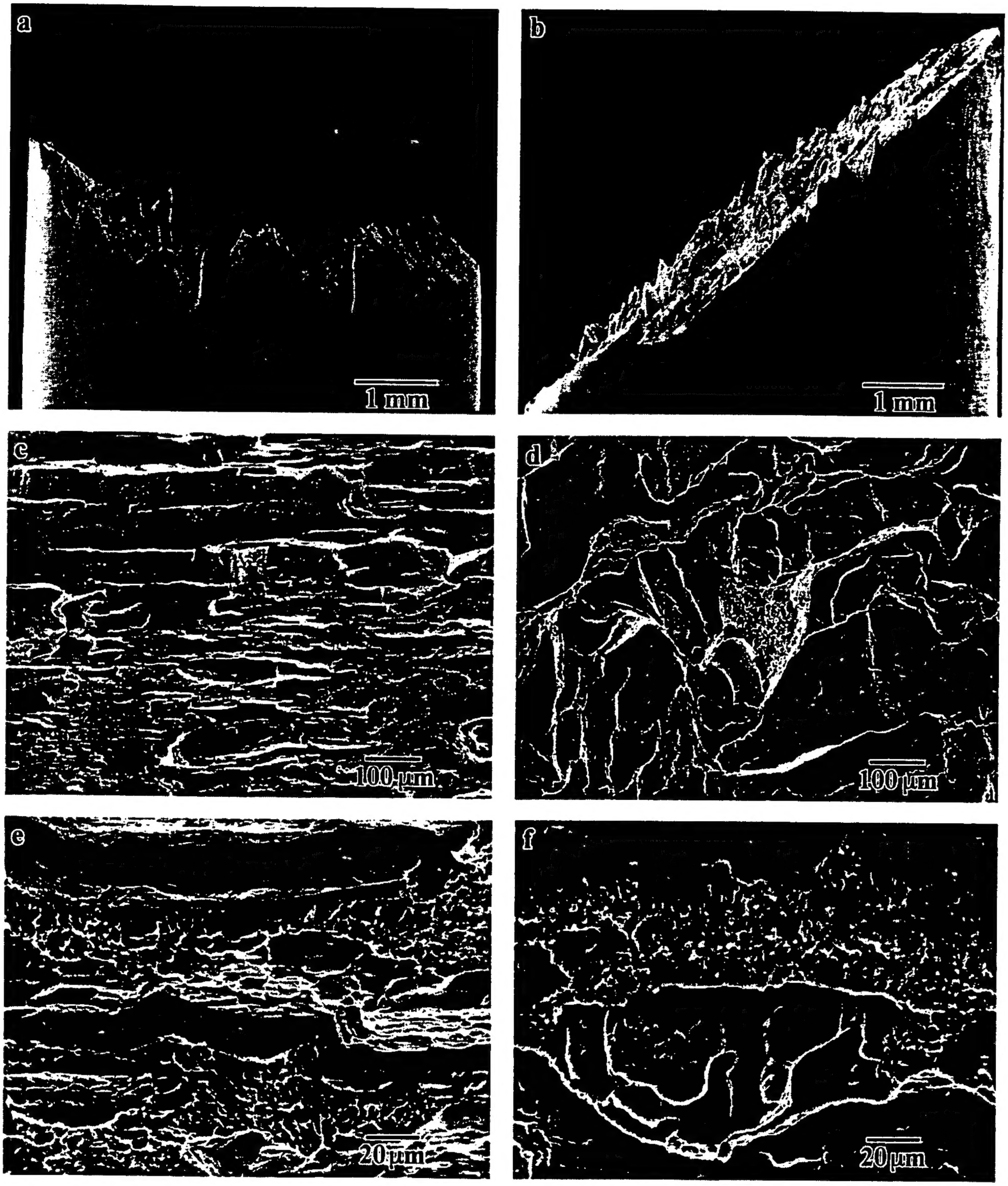


Figure 9: a, c, & e) SEM micrographs of the fracture surfaces for the AF/C 489-T36 alloy aged at 150°C for 24 hrs.
b, d, & f) SEM micrographs of the fracture surfaces for the AF/C 489 alloy pre-aged at 120°C for 8 hrs 20 minutes with a final age at 150°C for 21 hrs.

Table 1. Tensile Data for AF/C-489

Annealing Condition	Direction	σ_{YS}	σ_{UTS}	%El
As Received	Longitudnal	37.7 Ksi 260 Mpa	48.7 Ksi 337 MPa	18%
150°C 24 hrs	Longitudnal	68.54 Ksi 473 MPa	79.96 Ksi 551 MPa	5.37%
	Transverse	*57.88 Ksi* *399 MPa*	*76.15 Ksi* *525 MPa*	*4.25%*
100°C 24 hrs / 150°C 16.5 hrs	Longitudnal	64.02 Ksi 441 MPa	77.54 Ksi 535 MPa	7.43%
	Transverse	*52.10 Ksi* *359 MPa*	*74.87 Ksi* *516 MPa*	*6.76%*
100°C 24 hrs / 150°C 18 hrs	Longitudnal	63.41 Ksi 437 MPa	76.24 Ksi 526 MPa	7.28%
	Transverse	*51.95 Ksi* *358 MPa*	*73.49 Ksi* *507 Mpa*	*5.95%*
100°C 48 hrs / 150°C 18 hrs	Longitudnal	61.88 Ksi 427 MPa	76.01 Ksi 524 MPa	6.68%
	Transverse	*51.80 Ksi* *357 MPa*	*74.49 Ksi* *514 MPa*	*6.16%*
100°C 72 hrs / 150°C 18 hrs	Longitudnal	60.50 Ksi 417 MPa	76.09 Ksi 525 MPa	8.14%
	Transverse	*51.95 Ksi* *358 MPa*	*73.64 Ksi* *508 MPa*	*5.81%*
120°C 8 hrs 20 min / 150°C 21 hrs	Longitudnal	66.85 Ksi 461 MPa	77.79 Ksi 536 MPa	7.43%
	Transverse	*56.72 Ksi* *391 MPa*	*75.16 Ksi* *518 MPa*	*6.37%*
120°C 12 hrs / 150°C 21 hrs	Longitudnal	65.90 Ksi 454 MPa	77.56 Ksi 535 MPa	6.67%
	Transverse	*55.79 Ksi* *385 MPa*	*74.56 Ksi* *514 MPa*	*5.32%*